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Validation of Snow Extent Product from MODIS Data

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1. Introduction

The objective of this investigation is to validate the mapping algorithm for snow covered area (SCA) developed by the MODIS Team. Snow-covered area is a crucial input of the hydrologic and climatic modeling in seasonally snow-covered regions. Our investigation will assist monitoring of snow processes at scales from alpine watershed to regional and global scales. It has two phases, with phase I before MODIS image data become available and phase II after it.

In an attempt to develop or verify a snow-mapping algorithm, a common problem is lack of sufficient ground truth data. Most snow mapping algorithms were developed and validated with only limited "user-supplied" ground truth data that covers only a very small portion of snow-covered environmental conditions. This type of technique can not provide any information on evaluation of the algorithm performance and assessment of the accuracy of classification results where the ground truth was not available. It is clear that the key to validation of the MODIS snow extent product is to obtain a sufficient amount of ground truth data that covers different background targets, terrain, atmosphere, solar and sensor viewing geometry. Much of our efforts have been focused on this issue.

The ground truth of snow-covered area from our validation is obtained by high resolution digitized VNIR color photos. For a large portion, especially in alpine regions, it is represented as a fraction of snow cover at each MODIS 500m pixel resolution. The MODIS snow-mapping algorithm, however, uses a binary classification, i.e., a pixel will be identified either as snow or not-snow. This difference has resulted in a difficulty for quantitative comparison of the above two results. Our current validation was performed under the concepts of climatic and hydrological applications that use snow covered area as the model input. Since the project started in Nov. 1997, we have mainly focused on **1) Phase I validation - using simulated MODIS image data from Airborne (AVIRIS and MAS) data, and 2) examining the techniques to obtain the ground truth by using ASTER and TM for validation in Phase II.**

2. Phase I validation using Airborne image data

2.1 Summary of Airborne Data Validation Approach

The ground truth data is a key to any algorithm development and validation. Figure 1 summarizes the technique we used to carry out the Phase I validation. The detailed description for this technique is in [1] and [2]. We used the digitized high resolution VNIR color photo that is taken simultaneously with AVIRIS and MAS image data on ER-2. It covers about 15 km x 15 km. This film, originally referred to as camouflage-detection film, differs from conventional color film because its emulsion layers are sensitive to green, red, and near-infrared radiation (0.5 μm to 0.9 μm). Used with a yellow filter to absorb the blue light, this film provides sharp images and penetrates haze at high altitudes. The color infrared photo can be digitized to a three-band digital image with a pixel resolution from 1 to 4 m. Meanwhile, MODIS, ASTER, and TM image data can be simulated by using each sensor's spectral and spatial response functions. The snow mapping algorithms were then performed. In contrast with other techniques, such as low elevation aerial photo, the advantages of using color infrared photo are:

1) the color infrared photo and airborne image data are taken simultaneously
2) similar solar illumination and sensor viewing geometry since the instruments are on the same platform
3) covers large area

Thus, we can access large amounts of ground truth data of snow-covered areas and validate the accuracy of the snow mapping algorithm under a variety of viewing and illuminations, land cover types, atmospheric and terrain conditions.

2.2 Validation Using Simulated MODIS Data

Since 1994, we have collected 367 AVIRIS scenes with snow cover over different regions in North America. They cover a wide range of solar illumination, atmospheric, terrain, and snow conditions. Unfortunately, only about 20 % of our collected AVIRIS scenes have VNIR color photos available. To request those color photo is expensive - $2000 per flight-line. Our evaluation was performed on 67 AVIRIS scenes current available. These data acquired over the Sierra Nevada and South Cascades Mountain Ranges represent the environment of common alpine regions and were obtained from April to July, during melting season. The validation was performed on 1) the total snow fraction at AVIRIS scene scale, i.e., about 10 km by 12 km, and 2) the pixel-based validation. The former represents the case for climatic studies where we are only interested in the snow fraction of a grid but do not care about location inside of the grid, such as GCM input. The latter represents the case for hydrological studies where we need information not only on the total snow covered area but also on location.

Figure 2 compares the total snow covered area derived from the photo and estimated by the MODIS algorithm (1996) using 67 simulated MODIS data from AVIRIS scenes on the left. Note that the MODIS algorithm has been updated by including a module for forested area. The overall accuracy is 14.6 km^2 with a maximum error of 37.9 km^2, for which the corresponding fraction covers in a scene are 12.1 % and 31.6 %, respectively. It performed well at small fraction ranges. At large fraction range, its estimation has slightly larger error with over-estimation in most cases. For a grid of GCM models at regional to global scale, it generally is coarser than the AVIRIS coverage (10 km x 12 km). The finest regional GCM input is at a similar scale. The error is much less than the current techniques that were used to generate snow-covered area as the GCM input, such as that obtained using passive microwave sensors. Overall, the MODIS algorithm performed quite well in terms of estimating total snow covered area at a grid scale of AVIRIS scene coverage even in the alpine regions.

Therefore, we expect that the the MODIS will provide a reliable snow extent input for climatic studies.

The right side of Figure 2 shows a histogram of the Root Mean Square Error (RMSE) from each scene by means of pixel-based comparison. That is, each RMSE value was obtained by evaluating every pixel in a simulated MODIS scene. The overall RMSE for all scenes is 25.1 %. In most cases, the RMSE for each scene ranges from 20 % to 30 %. A good binary snow classification algorithm classifies a pixel as the snow when snow fraction is greater than 50 % and as snow-free when it is less than 50 %; the RMSE from a scene will be around 25 %. Under this condition, the error might be canceled out if the error were randomly or uniformly distributed. As a result, the MODIS algorithm gives quite accurate results in terms of estimating total snow covered area in a scene. Thus, it indicates that MODIS algorithm is a very good binary classifier.

However, a common problem with a binary classifier under effects of "mixed" pixel is that the probability of a pixel to be classified as snow is proportional to snow fraction in a pixel. The more snow cover is in a pixel, the more likely it will be classified as snow. The spatial distribution of snow cover in a mountain area depends upon elevation, surface orientation, and the intensity and direction of wind. It is, in general, characterized as full, large fraction, and small fraction at high, middle, and low elevation zones. To demonstrate this common problem, we show Figure 3. From left to right, they are snow fraction image from the color photo, snow cover image from the MODIS algorithm, and the difference between these two maps (left – middle) at MODIS pixel resolution. The brightness in the difference image (bottom right) ranges from – 90% (black color) to 53% (white color). It represents an over-estimation (black) or under-estimation (white color) of snow cover fraction in % at that pixel. The gray color indicates that there is no difference between these two. There is no significant difference at the regions near the center of the ice field or at high elevations where the pixels are fully or near fully covered by snow. Going from high elevation to low elevation (or departing from the center ice field), the brightness in the difference image becomes darker, indicating the algorithm over-estimate snow cover in these regions. At low elevation or near the edges of ice fields, the brightness suddenly changed from black to white indicating under-estimation in these regions. It is clear that both over- or under-estimations are caused by the “mixed pixel” problem.

In addition, we can also see a large range of RMSE with a maximum 49.5 % in the right side of Figure 2, which indicates the effects of different environmental conditions on the algorithm performance. The large range RMSE also indicates that we need a large amount of ground truth data for after-launch validation since validation from only a few scenes might result in a wrong conclusion. In other words, it requires a large sample to infer the correct conclusion.

3. Evaluation of Accuracy by Using ASTER and TM for MODIS Ground Truth

From the small amount of airborne data that we might expect from the limited airborne campaigns for after-launch validation, we might get a wrong conclusion since the RMSE in pixel-based validation had large variations depending on environmental factors. Therefore, we have switched our attention to investigate the techniques to derive ground truth by using ASTER and TM so that the after-launch validation can be carried out with sufficient image data at different environmental conditions. For this task, we have evaluated two major techniques based on the classification concept: 1) evaluating the current available classification algorithms and 2) using the spectral unmixing technique.

3.1 Evaluation of the Available Classification Algorithms

To evaluate the feasibility of using high resolution image data (ASTER and TM) using the current available classification techniques to obtaining the ground truth of snow covered area, we performed 1) TM-MODIS algorithm (1996), 2) Rosenthal and Dozier's regression tree algorithm (1996), and 3) a binary classification algorithm that uses only three of ASTER's 15m visible-near-infrared bands. The evaluation was carried out by first classifying the pixels at ASTER or TM (simulated using AVIRIS) resolution scales, i.e., 15m or 30m. Then the classification results were re-sampled to MODIS 500m resolution in order to evaluate the pixel-based comparison. Meanwhile, the total snow covered area or percent of snow cover in each scene was also calculated. Similarly, the corresponding snow cover ground truth derived at AVIRIS resolution scale from high resolution color infrared photo was re-sampled to MODIS 500m pixel resolution. Table below shows the RMSE of the overall and maximum errors in % from 67 AVIRIS simulated scenes. The second and third columns represent the comparison for overall and maximum errors in % of estimating the total snow-covered fraction of the AVIRIS coverage. The last two columns are for the pixel-based comparison, also in %.

	Percent of Snow cover		**Pixel Based Compariso n**	
	Overall	*Max.*	*Overall*	*Max.*
MODIS	7.4	20.2	15.6	30.4
Rosenthal's	6.7	22.2	14.2	28.8
ASTER	4.8	12.6	12.6	22.5

Table. Validation of the current available TM and ASTER algorithms from 67 AVIRIS simulated scenes.

In comparing the MODIS algorithm performance at TM 30 m and MODIS 500 m resolution scales, the accuracy in both estimation of total snow-covered fraction for a scene and the pixel-based comparison is significantly improved because the effects of the "mixed" pixel problem have been greatly reduced. A slightly better result than the MODIS algorithm was obtained from Rosenthal's algorithm. However, this algorithm was developed from TM data at Sierra Nevada areas and a larger portion of the AVIRIS data used in this evaluation was from this site. Therefore, we concludes that both algorithms have similar accuracy in terms of using TM to derive the snow covered fraction and pixel based ground truth at MODIS 500 m resolution scale. Furthermore, the most accurate results can be obtained by using ASTER's three 15m visible and near-infrared bands, largely due to a better spatial resolution than TM data.

3.2 Development of Unsupervised Unmixing Technique for ASTER

The derived apparent reflectance, such as from AVIRIS, MODIS and ASTER, is usually a function of local solar illumination angle, surface orientation, and sensor viewing geometry, in addition to atmospheric effects. Terrain has a great impact on the imaged pixel size. In alpine regions, the great variations in elevation and surface orientation from pixel to pixel consistently result in a great variation in the derived surface apparent reflectance. This variation due to topographic effects unrelated to the spectral reflection properties of surface cover type has great impact on classification accuracy and on spectral linear unmixing.

Linear spectral unmixing techniques have been applied to snow-covered area classifications. The major difference in these studies is the techniques for selecting spectral endmembers. Our analyses of terrain effects on spectral unmixing indicate that each current technique for selecting the reference spectral endmembers has its own advantages and disadvantages under mountainous areas.

1. Scene-selected spectral endmembers by either manually averaging from training sites or by using convex geometry technique
    - Advantages: less sensitive to system noise, error in atmospheric correction, local spectral endmembers
    - Disadvantages: terrain and illumination effect in the selected endmembers
2. Spectral library by either field measurements or model simulation
    - Advantages: the normalization can be used to reduce terrain effect
    - Disadvantages: limited available data, affected by system noise, illumination, and difference between model predictions and measurements

By taking advantage of each approach, we developed a technique for automatic selection of local reference spectral endmembers. The detailed description of our newly developed technique can be found in [3-4].

Figure 4 compares snow-covered maps derived from the simulated ASTER image data (left) and derived from high-resolution near-infrared color photos (right). The ASTER 9 band visible-infrared image data was simulated from an AVIRIS scene by using ASTER's spectral response functions and re-sampled to 30-m resolution. The brightness is proportional to snow fraction at each pixel. The black regions are snow-free. This example represents a case where snow cover is characterized by a continuos spatial distribution. Most of the snow cover is 100 % snow. The mixed pixels mainly occur at low elevation. At high elevations, the snow mixed pixels are mainly distributed at high surface relief or large slope areas. In this example, 3.8 % of snow-free pixels were mis-classified as the snow mixed pixels. 1.3 % of the snow mixed pixels were mis-classified as snow-free. The error for estimating total snow covered fraction and the RMSE for snow mixed pixels are 1.7 % and 6.4 %, respectively. Overall evaluation for all available scenes is underway.

4. Outline of Current Status and Future Directions

Due to the complexity of the Earth’s surface, the largest errors of the MODIS algorithm are expected to occur mainly in rugged alpine and forest regions. Our current evaluation was performed from data representing alpine environments with one of the worst conditions for the MODIS snow-mapping algorithm. We will continue Phase I validation using airborne image data from AVIRIS and MAS.

1. Current status
   - Have finished the initial analyses of AVIRIS data
   - Evaluated the possibility of using the available binary classification algorithms to derive ground truth for after-launch MODIS validation by TM and ASTER
   - Close to finishing up the development of spectral unmixing technique for using ASTER to obtain the ground truth for after-launch MODIS validation in alpine regions
2. Directions:
   - Update MODIS new algorithm for forest area
   - Analyze MAS image data for off-nadir viewing environments
   - Detailed analyses on how environmental factors affect the MODIS snow mapping accuracy
   - Extend ASTER spectral unmixing technique to TM and MODIS

In phase II, we will use the data from ASTER and Landsat TM to obtain ground truth data by using the most accurate technique identified in the Phase I study. The ASTER data request has been approved by ASTER team over three years at our King's River test site in the Sierra Nevada, California. In addition, we have 1) requested several AVIRIS flight-lines for spring 2000, and 2) submitted a proposal to request EO-1 data at our test site.

Publications

[1] J. Shi and Z. Li, Validation of MODIS snow mapping algorithm using AVIRIS image and Near-infrared color photo, in *Proceedings of SPIE'98*, Ed. Robert O. Green and Qingxi Tong, The International Society for Optical Engineering, vol. 3502, pp. 243-250, Beijing, Sept. 1998

[2] Z. Li and J. Shi, Establishment of a database for development and validation of snow mapping algorithms, to be published in *Proceedings of Fourth Remote Sensing in Hydrology*, Santa Fe, Nov. 1998

[3] J. Shi, Estimation of Snow Fraction Using AVIRIS Simulated ASTER Image Data, to be published in *Proceedings of Eighth Airborne Geoscience AVIRIS Workshop*, Ed. Robert O. Green, Feb. 1999

[4] J. Shi, Snow Fraction Estimation in Alpine Regions Using AVIRIS Simulated ASTER Image Data, to be published in *Proceedings of IGARSS'99*, Hamburg, Germany, June, 1999

Figure 1 Summary of Airborne technique. *The airborne data and the digitized color infrared photo were taken on July 19, 1994 on the alpine glaciers over Cascades Mountain Range, in Washington, U.S. The top row left and middle show the digitized VNIR color photo and its land classification map. The color coding are snow as white, forest - dark green, short vegetation - green, bare surface - brown, lake - blue, shadow and unclassified pixels - black. The top right shows the snow map that was a resample at 500 m resolution MODIS scale. The brightness is proportional to percent of snow cover. The bottom row shows the three bands AVIRIS image, the simulated MODIS image data, and the estimated snow cover by MODIS algorithm.*

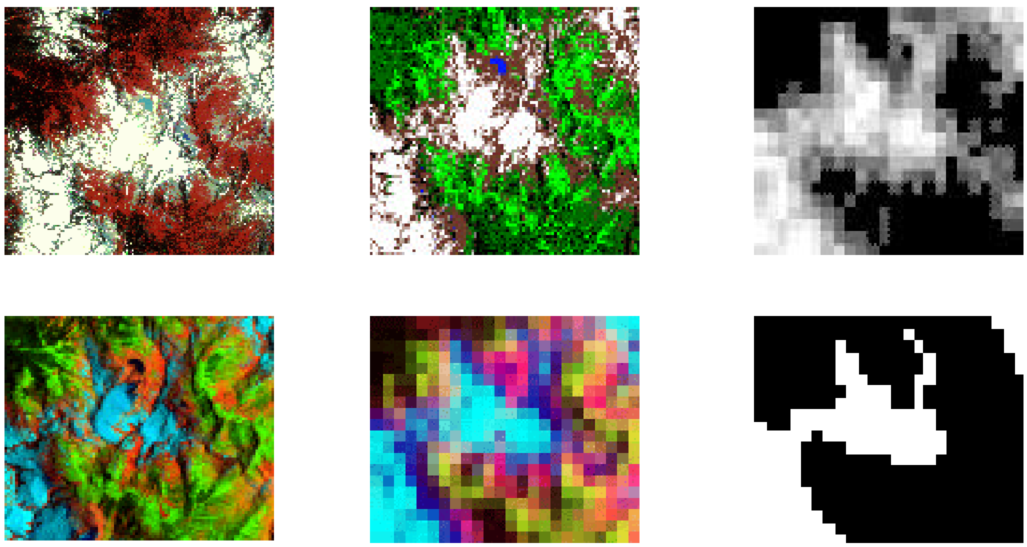

Figure 2. *Validation using simulated MODIS by AVIRIS image data. Left side is validation in total snow covered area in km^2 and right side is RMSE in % from each scene in term of pixel based comparison*

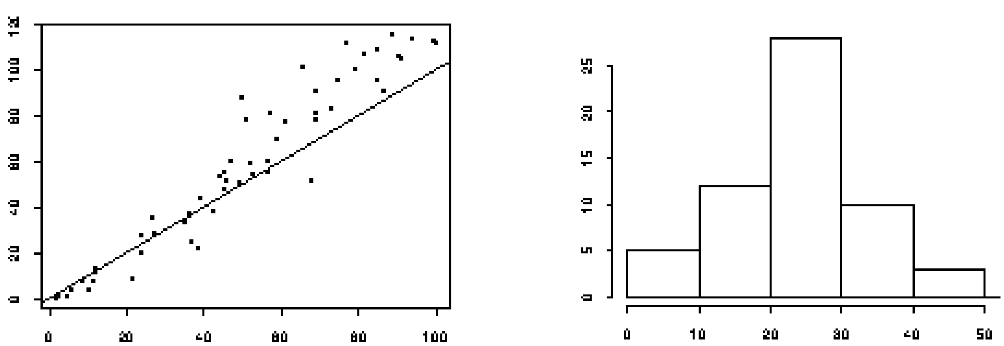

Figure 3. The MODIS derived snow map on left, snow map from photo in middle, and the difference on right.

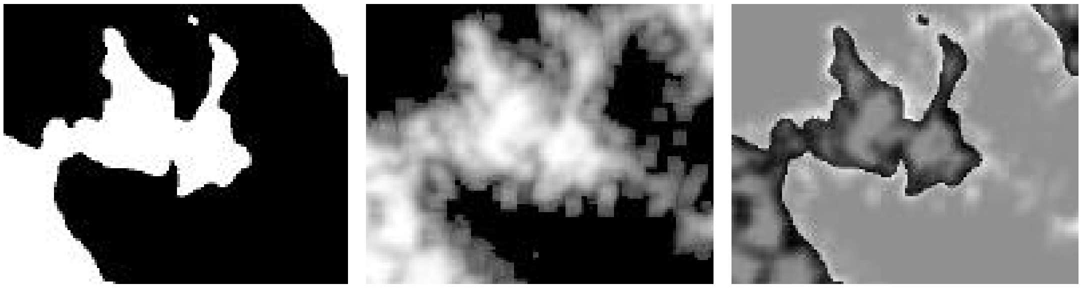

Figure 4. Snow map from photo on left, and snow map derived using spectral unmixing technique with simulated ASTER data